USAID Climatological Overview - Peru

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Introduction

The country of Peru is located in northeastern South America, situated just south of the Equator with its western border adjoining the Pacific Ocean. The climate of Peru is notably diverse; the Andes Mountains range runs north to south through the center of the country, forcing extreme regional differences in temperature and precipitation. The westernmost part of the nation, the coast and Altiplano, is characterized by arid conditions and widespread desert-like conditions. Moving eastward, the Andes mountains sharply rise from the ocean, and host many of the glaciers which provide a large portion of the nation's water supply. To the east of the Andes is the Amazon rainforest, an area well known for its wet and tropical conditions. These three general regions, that is, the deserts, the Andes, and the rainforest, define the most notable components of the Peruvian climate, and are the drivers for the disparate lifestyles and climatological concerns nationwide.

Just as the climate varies dramatically across regions, the main industries and livelihoods are equally discrete. Peruvians principally rely on four industries: fishing, agriculture, mining, and manufacturing/construction (IRG, 2011), the first two of which are highly vulnerable to climate change. Proficiently understanding the extent to which climate change impacts these sectors is crucial to forecasting the well-being of Peruvians. In order to determine how society will be affected, it is necessary to interpret the underlying climate dynamics, interannual trends, and long-term variability through review of climatological data and analysis of future model forecasts.

Methodology

To evaluate the climate of Peru as a whole, the country may be divided into three climatologically similar regions which together effectively represent the diversity of the landscapes (Fig. 1). In each region, historical data may be regressed and extrapolated out into the future. Relatedly, future climate in the next decade may be marginally well forecasted through use of the International Panel on Climate

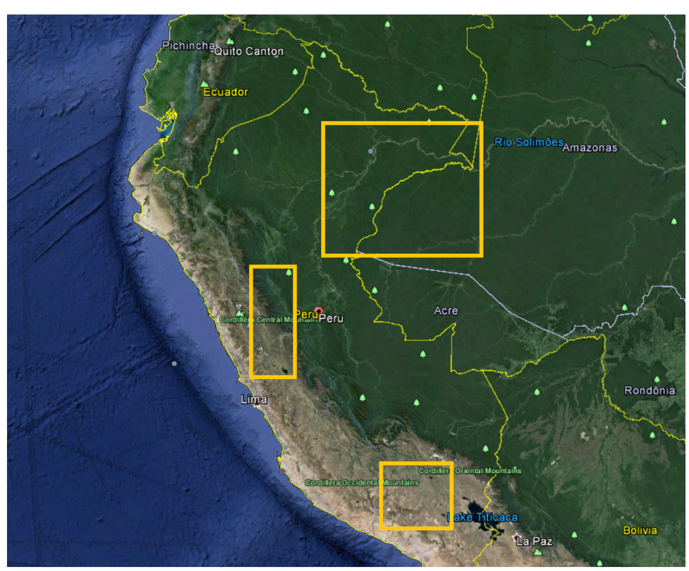

FIG. 1. Three subregions of Peru; the rainforest, the Andes and the

Change's (IPCC) Coupled Model Intercomparison Project Phase 5 (CMIP5) multimodel ensemble of global circulation models. Beyond observations of precipitation and temperature, certain indicators can be directly associated with Peruvian climate. The El Niño Southern Oscillation (ENSO) in the Pacific Ocean directly impacts the entire country, and can be forecasted with some skill. In this study, historical data was utilized to model past climates (hindcast), and the CMIP5 RCP 8.5 (only available scenario) was used for future expectations.

Historical data and future models for each of the regions was found in the International Research Institute (IRI) for Climate and Society's Data Library and Maproom. The variability of the Peruvian climate was categorized by trend (the "climate change" signal), decadal variability, and interannual variability (including ENSO). Climate change explained 1% of the variability, while natural decadal and interannual variabilities accounted for 66% and 32% respectively (Fig. 2a,b,c). Peru's precipitation variability is not influenced by climate change (0% explained), with

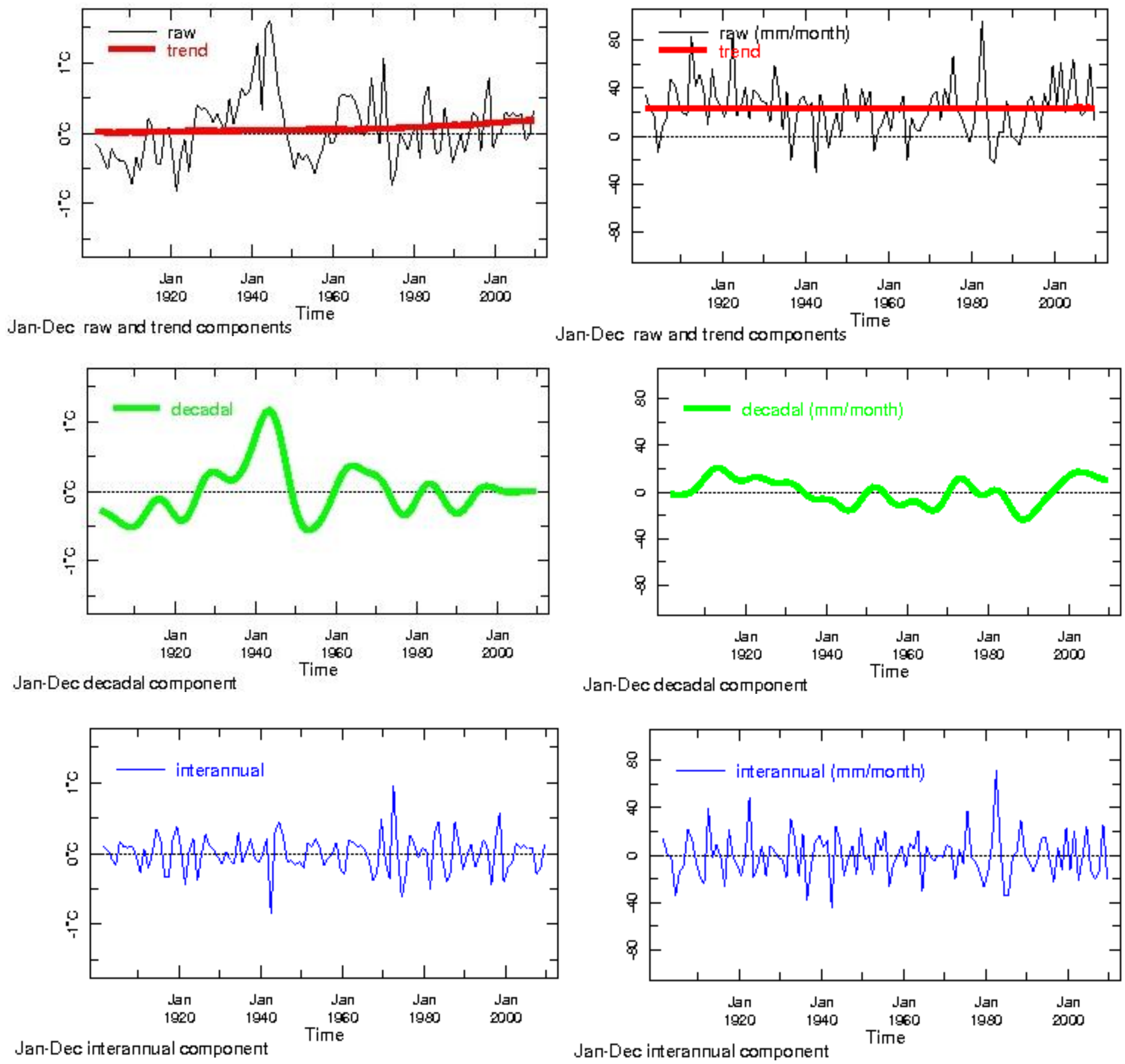

FIG.2 (a) temperature trend (b) temperature decadal variability (c) temperature interannual variability (d) precipitation trend (e) precipitation decadal variability (f) precipitation interannual variability the majority being explained by natural decadal variability (25%) and interannual variability (72%) (Fig. 2d,e,f). These results highlight the significance of identifying the drivers of decadal and interannual variability when looking to forecast climate into future years.

Climatology and Model Validation

Peru has two seasons, wet and dry, which peak from January to March (JFM) and June to August (JJA) respectively. Current climatology for precipitation, according to the University of East Anglia Climate Research Unit (UEA CRU) observational data analyzed from 1948 to 2012, ranges between a minimum of approximately 120mm/month to a maximum of 280mm/month. Dry season precipitation ranges between 60 and 130 mm/month.

A hindcast of the period 1901 to 2005 was performed using the IPCC CMIP5 models to evaluate model skill across the country (Fig. 3). This analysis revealed that temperature was simulated well in the foothills of the Andes mountains and on the coastal regions, but generally underpredicted temperature by up to 4°C in the Amazon rainforest. The Andes tended to be modeled 4° to 18°C warmer than the temperatures observed. Additionally, the southern desert was on average modeled 8° to 18° warmer (Fig. 3). The hindcast inaccuracy may be attributed to the models' inability to capture the Andes mountain range accurately. The Andes stand at a maximum height of 6,960m, being 200 to 700km wide, and approximately 200km away from the Pacific (Denevan, 2012). CMIP5's spatial resolution is 0.5° by 0.5° (approximately a 2,500km2 grid box at the equator). Despite the high spatial resolution, the models have difficulty capturing the narrow ridge and high altitudes of the Andes mountains and therefore underestimate the altitude and overestimate temperatures (Xu, 2004).

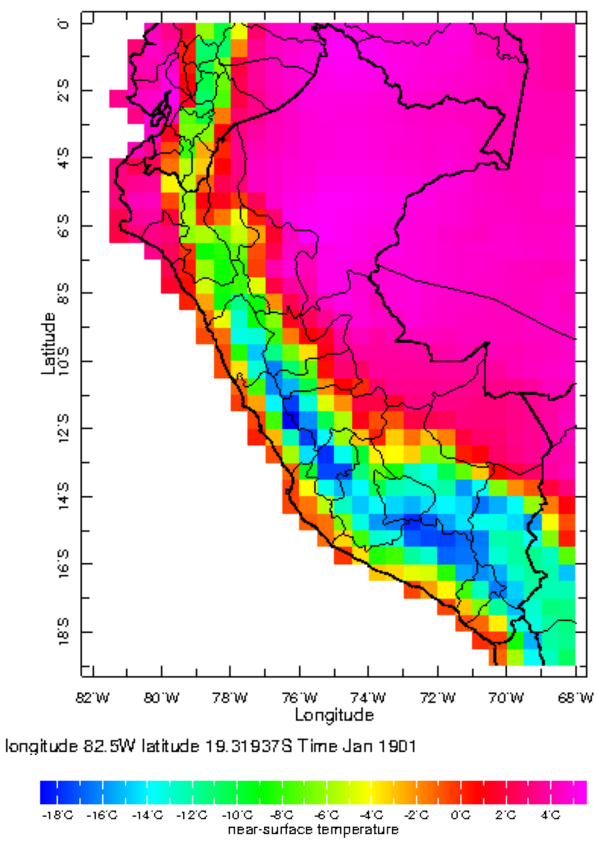

FIG. 3. Evaluation of temperature simulation skills within IPCC CMIP5 models for the period 1901-2005

Qualitative analysis of a precipitation hindcast using observational UEA CRU data showed little correlation between the spatial distribution of precipitation. The CMIP5 models overestimated precipitation along the northern coast, which corresponds to Hirota et. al's findings in their 2011 study of CMIP3 modeled tropical pacific rainfall. In the study an overestimation of high subsidence region precipitation, whilst and underestimation of precipitation in convergence zones was found (Hirota, 2011). Visual analysis revealed that CMIP5 acted similarly in over estimating precipitation at the northern coast of Peru and underestimating rainfall in the northern Amazon rainforest. Additionally, precipitation patterns did not match in the Andean mountain and altiplano regions. Peru's southeastern Amazon region's high rates precipitation were partially captured, as were the southern coastal region's rainfall deficits at the margin of the Pacific. Overall, the CMIP5 model has little skill in modeling the majority of Peru's climatological regions, which may be attributed to geographic variety and atmospheric conditions of the country (Hirota, 2011).

Arid to Semi Arid Desert Climatology and Future Projections

The western region of Peru, bordering the Pacific Ocean, has an arid climate driven mostly by the Humboldt Current's upwelling of cool, nutrient-rich deep ocean water. This keeps the temperature of the region relatively mild and dry, as the cool water is not conducive to convective processes resulting in precipitation (the deserts are also in the subsidence zone of the subtropical high-pressure cell) (Houston, 2003). As a result, the western and southern parts of the country may be classified as arid or semi-arid. To get a representation of this portion of the country, a sample grid was chosen to serve as proxy for the entire region as a whole. The specific grid ranged from 75° 15' W to 70° 30' W and 18° 30' S to 16° S, and is located in the southern desert and Antiplano region. It should be noted that the southern desert is spatially larger than, and can differ substantially from, the coastal margin; this area was chosen for analysis to ensure sufficient data and model resolution in an arid region.

The climatology of the Peruvian desert regions include average monthly temperatures ranging from 13° to 17°C annually (Fig. 4a), and negligible rainfall April through November. Precipitation during the wet season (December to March) in this region generally does not exceed 50mm/month (Fig. 4b).

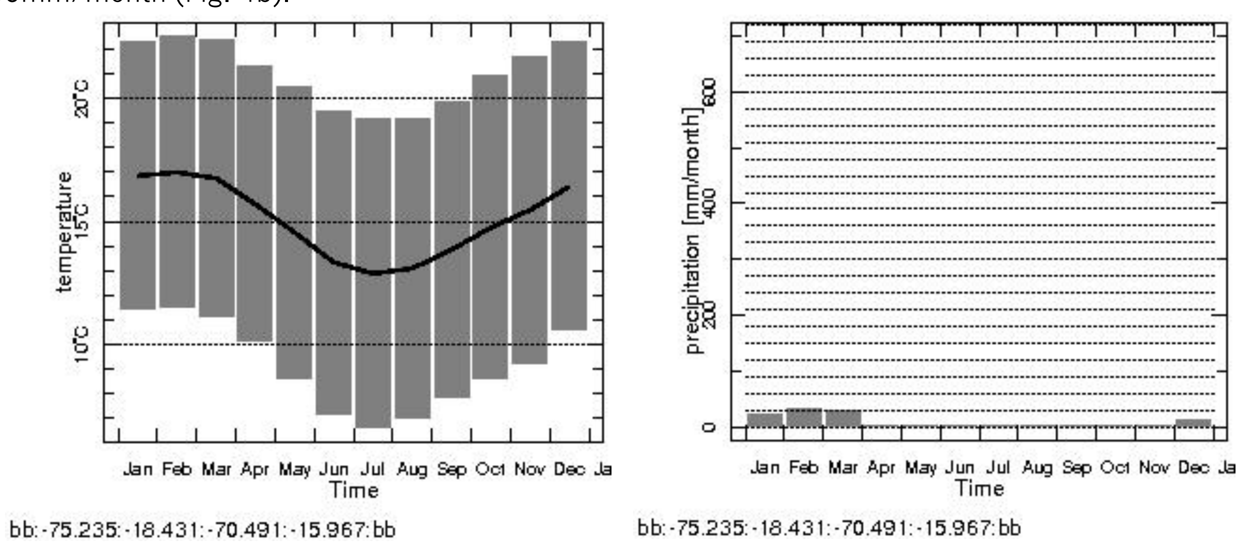

FIG. 4. (a) Monthly mean temperatures of desert regions. (b) Monthly mean precipitations of desert regions.

The CMIP5 2006-2099 forecasts for temperature during the wet and dry seasons in Peru both indicate a linear warming trend of approximately 4°C over the next 95 years (Fig. 5a,b) . These values can be expected to be accurate within an order of magnitude according to the previous model validation performed for this climate zone in Peru, and the trend appears reliable. Precipitation in the indicated arid southern desert during the wet season and dry season appears to remain consistent with current climatology (Fig. 5c,d). Although the fidelity of precipitation modeling in Peru is questionable, the southern desert and altiplano region's projections have moderate skill.

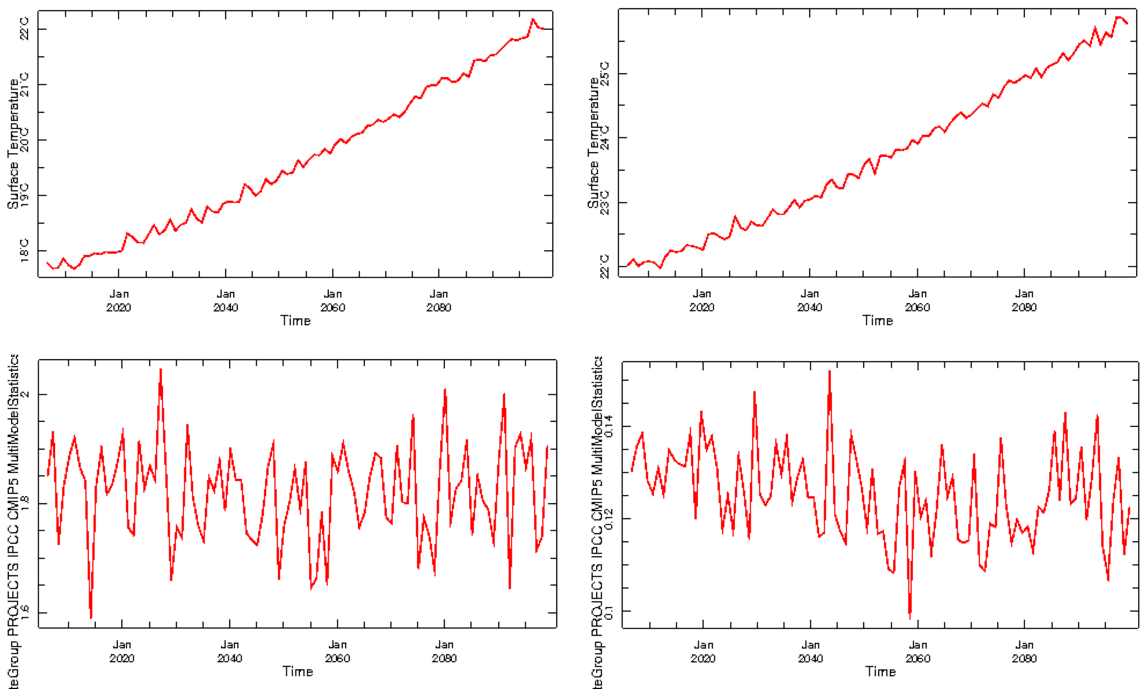

FIG. 5. (a),(b) CMIP5 forecasts for temperatures in wet(JFM) and dry(JJA) seasons of desert regions for the period 2006-2099. (c),(d) CMIP5 forecasts for precipitations in wet(JFM) and dry(JJA) seasons of desert regions for the period 2006-2099.

Amazonian Tropical Rain Forest Climatology and Future Projections

The eastern portion of the country is dominated by the tropical Amazon rainforest with high annual precipitation. The local climate here is driven principally by the Atlantic air mass which rains out when it meets the Andes, depositing heavy rainfall and bringing warm, humid conditions to Eastern Peru (IRG, 2011). This type of landscape covers a large portion of the country, yet the selected sample region was restricted to 76°W to 69° 30' W and 9° 45' S to 2°S.

The selected Amazonian rainforest zone includes monthly climatological temperatures ranging from approximately 19° to 31°C annually (Fig. 6a). Precipitation during the wet season is 250 mm/month and dry season rates are between 100 and 150 mm/month on average (Fig 6b).

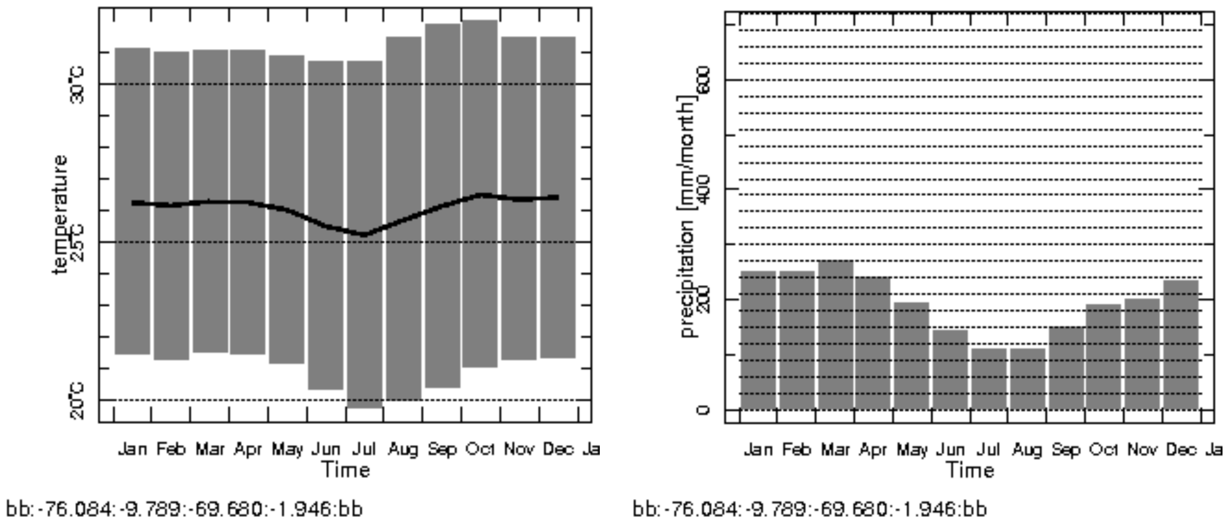

FIG. 6. (a) Monthly mean temperatures of rainforest regions. (b) Monthly mean precipitations of rainforest regions.

An upward temperature trend of approximately 4°C from 2006 to 2099 is projected by the CMIP5 models (Fig. 7a). As found during the hindcasts, models perform well for temperature in the Amazonian zone. A positive trend in wet season precipitation and negative trend during the dry season initiated by mid-century (Fig. 7b). According to the model validation performed at the start of our study, the reliability of the precipitation amounts and trends is uncertain. Generally, rainfall in this climate zone tends to be underestimated by the models.

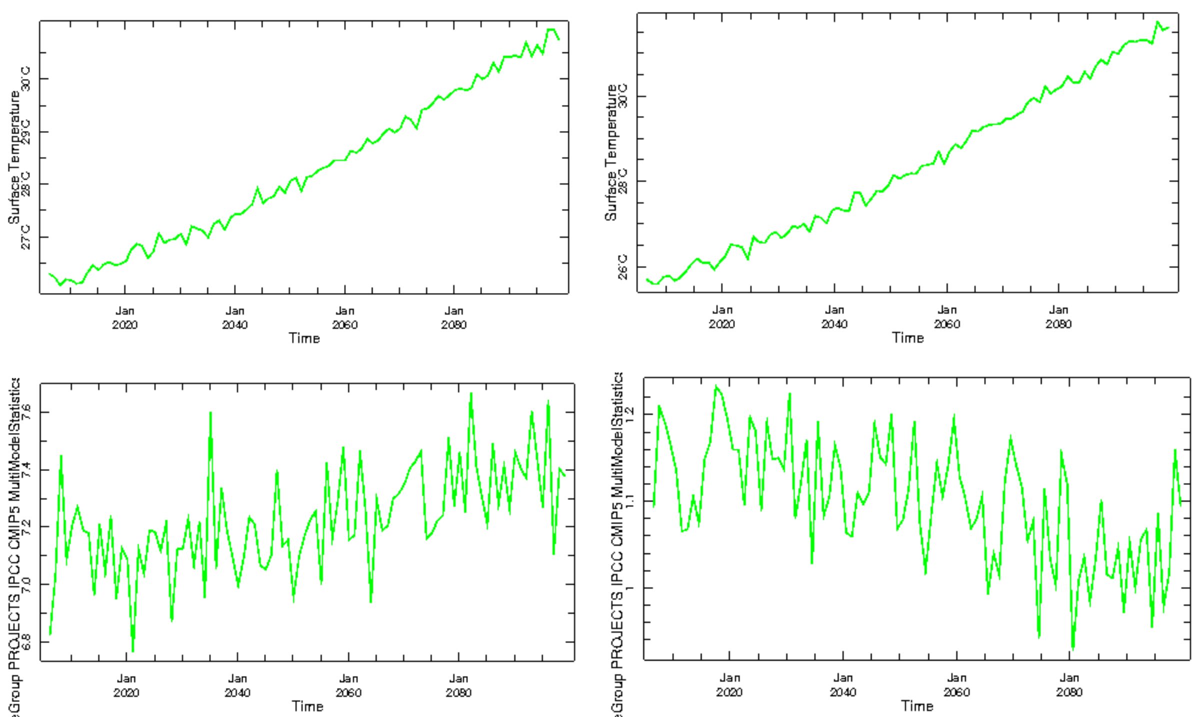

FIG. 7. (a),(b) CMIP5 forecasts for temperatures in wet(JFM) and dry(JJA) seasons of rainforest regions for the period 2006-2099. (c),(d) CMIP5 forecasts for precipitations in wet(JFM) and dry(JJA) seasons of rainforest regions for the period 2006-2099.

Andean Highlands and Mountains Climatology and Future Projections

The Andes Mountains, which divide the dry west and moist east, experience the coldest temperatures of the country and maintain mountain glaciers. Glaciers are rapidly retreating and are vital to supplying freshwater to the people of Peru (IRG, 2011). The Andes are particularly sensitive to climate change, which is most pronounced in the highest elevations where the glaciers reside. Due to the importance of these glaciers feeding freshwater to the population, the nation as a whole is therefore especially vulnerable to climate change (IRG, 2011). Local climate is highly variable from location to location; however the representative section of the Andes was evaluated as the climate between 77° 45' W and 76° 30' W and 10° 30' S and 7° 30' S.

The average temperature of the Andean mountain region is relatively constant throughout the year, and ranges from 4° to 22°C (Fig. 8a). Precipitation peaks in the wet season at about 150 mm/month, and is at a minimum during the June-July-August dry season (Fig. 8b).

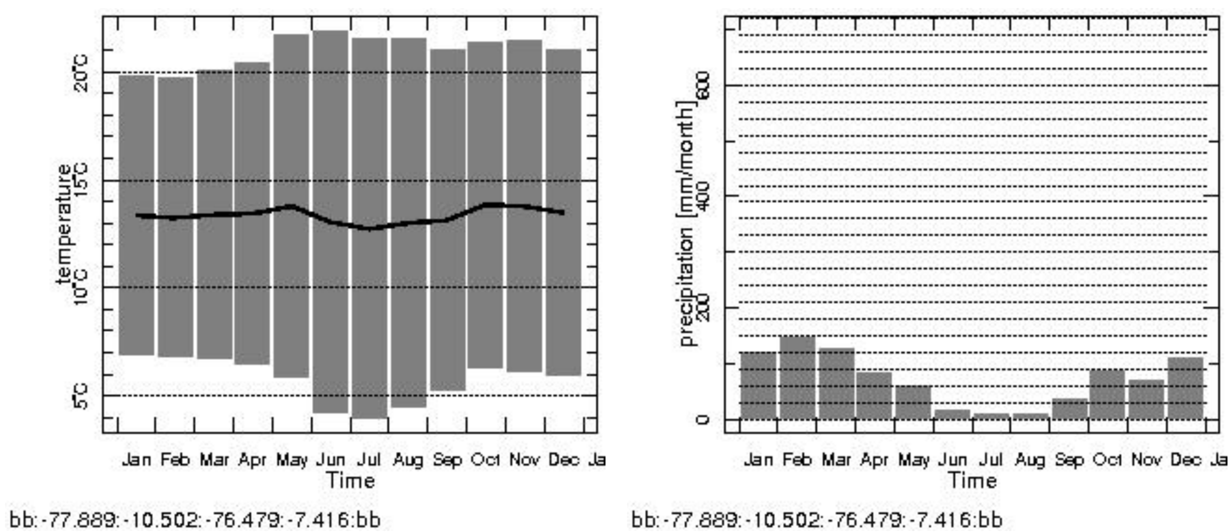

FIG. 8. (a) Monthly mean temperatures of the Andes region. (b) Monthly mean precipitations of the Andes region.

The temperature trend in the Andes region follows the same projected warming pattern as in the desert and rainforest of 4°C over the 95 year period (Fig. 9a,b). Wet season precipitation appears to mildly increase, while a projected trend in the dry season is not evident (Fig. 9c,d). As noted when analyzing the accuracy of the models, the Andes are poorly modeled for both temperature and precipitation, therefore the dependability of these projections are not certain.

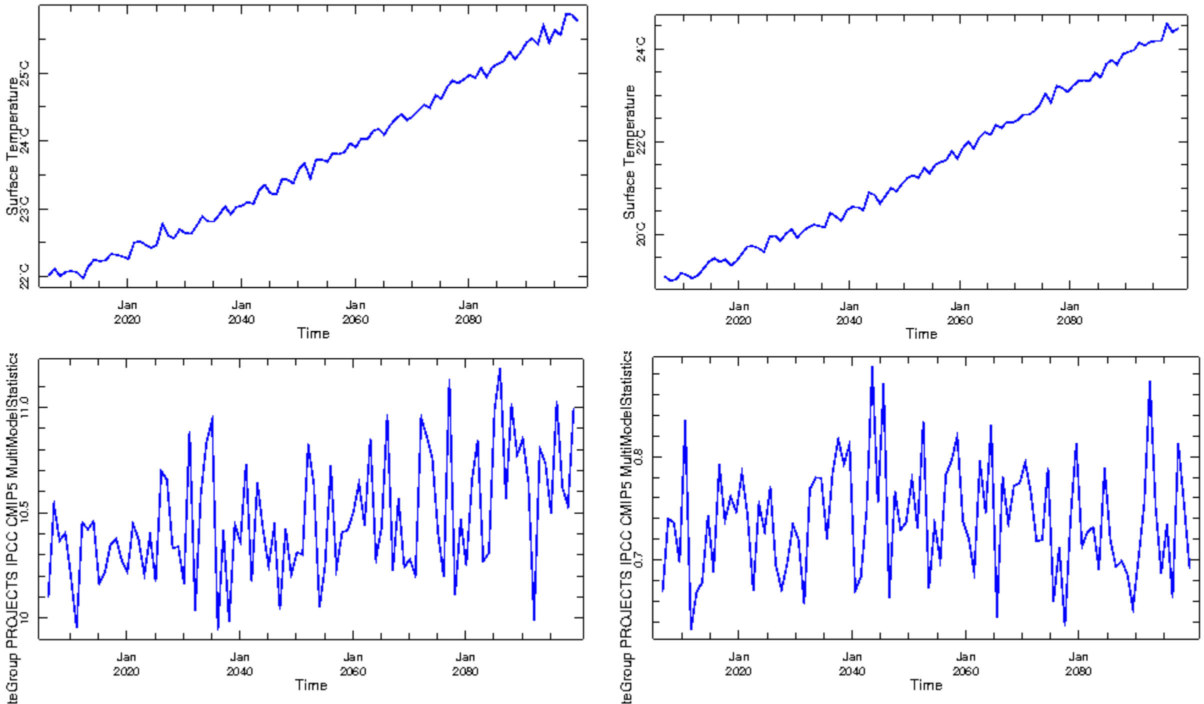

FIG. 9. (a),(b) CMIP5 forecasts for temperatures in wet(JFM) and dry(JJA) seasons of the Andes region for the period 2006-2099. (c),(d) CMIP5 forecasts for precipitations in wet(JFM) and dry(JJA) seasons of the Andes region for the period 2006-2099.

The Peruvian Andes have more than 70 percent of the world's tropical glaciers, with most being located in the Cordillera Blanca in the north of the country. Over the last thirty years, Peru has lost 22 percent of its total glacier area, accounting for an estimated reduction of 12 percent of freshwater for the coastal zone (Vasques, 2004). Monitoring of glacier discharge from the Cordillera Blanca has shown that such changes are already taking place and that increased runoff is accompanied by glacier thinning and supplied by non-renewed glacier melt. Scientists at Ohio State using isotope analysis found that the contribution of glacial melt has already surpassed its maximum level and is now declining (Mark, 2011).

Glacier mass balance, a key index to measuring glacier conditions, is defined as the difference between winter snowfall and amount removed during summer months. Inter-annual timescales glacier mass balance is strongly influenced by the ENSO phenomenon. Mass balance anomalies tend to be negative during El Niño and positive during La Niña events (Vuille, 2008) (Fig. 10).

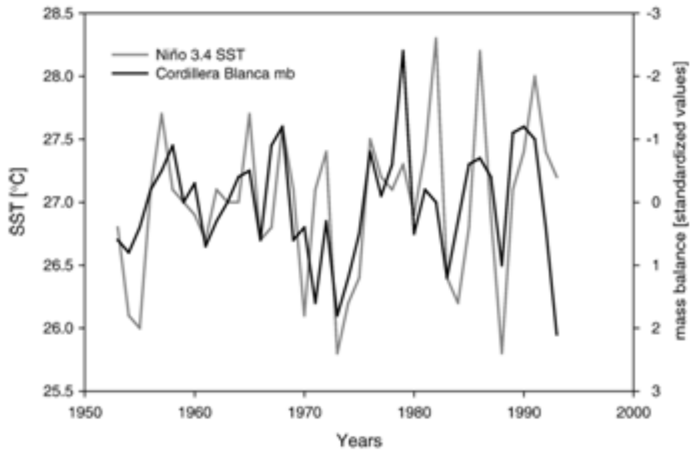

FIG. 10. A high correlation exists between the mass balance of Andean glaciers and El Niño oscillations. From Bryan et al., 2005.

Despite the coarse modeling from the CMIP5 that poorly models the Andes, a review of more specialized and localized models have indicated that the Cordillera Blanca will continue to shrink significantly over the next decades, with drastic consequences for runoff (Juen et al., 2007). Peru's National Meteorology and Hydrology Service SENAMHI's data predicts that glaciers will lose up to 37 percent of their current area by 2030 (IRG, 2011). This loss of runoff to the communities dependent upon its flow will have far-reaching repercussions.

El Nino Southern Oscillation

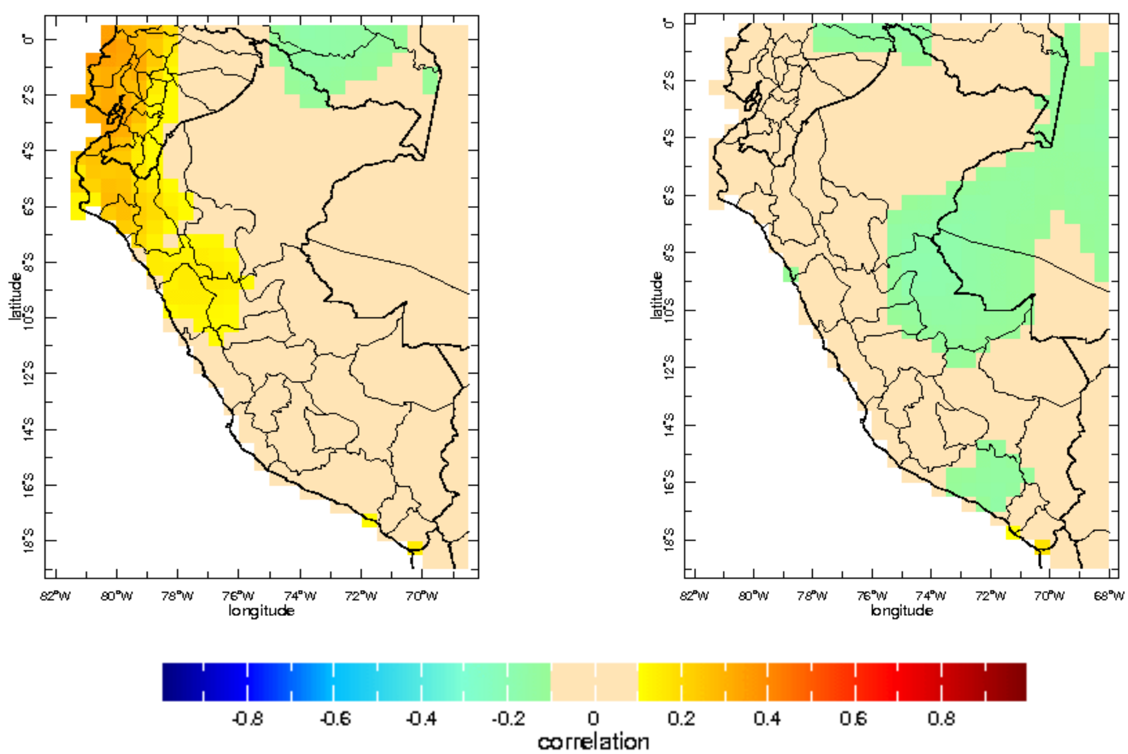

FIG. 11. Correlations between SST and precipitation

While some underlying decadal trends do exist that are forcing the precipitation and temperature in each of the regions of Peru, an interannual phenomenon, ENSO, has a large impact on the entire country's climate, but to varying degrees in different places.

El Niño affects the probability of flooding along the coast of Peru and drought in the Altiplano. Effects on increased precipitation are channeled through two main mechanisms. The first of these mechanisms is the warming of coastal waters and the second is the weakening of the south Pacific high and concurrent movement of the Intertropical Convergence Zone to the south (Tapley and Waylen, 2009).

Regionally, during an El Niño event, Fig. 11 shows a positive correlation between SST and precipitation along the mid-northern coast, which is strongest in the northernmost tip. This is supported by Tapley and Waylen (2009) who found that during an ENSO event, stations positioned along the coast experience increased annual mean precipitation of 88% and that the strongest of these increases are in the northern portion of the country.

Fig. 11 also describes a negative correlation between SST and precipitation in the Altiplano region. This is in agreement with Tapley and Waylen (2009) who find an annual decrease in precipitation of 18% in the Altiplano during an El Niño event. Droughts in this region were witnessed during the 1982-83 El Niño event (Tapley and Waylen, 2009). Once again, the effect of climatic perturbations is anomalous across the country, although ENSO events follow a regular pattern and its specific ramifications can be fairly well anticipated on a short time horizon.

Discussion

As climate change advances, each of the aforementioned regions will be especially impacted in one sector or another. Of the major components of the Peruvian economy, agriculture and fishing are most vulnerable to the expected climate changes in the near future. Additionally, the entire population is at risk of losing its primary water source in the glaciers. The extent to which each sector is impacted depends a great deal on which region it is located in and what changes are anticipated.

The majority of Peruvian agriculture is produced in the coastal zone to the West of the Andes (IRG, 2011) and is thus dependent upon the precipitation received since this is a traditionally recognized arid zone. The agricultural sector is vital to Peru not just for subsistence but also for exportation and consequently, both GDP and national food security are intertwined with climate. On the North Coast of Peru, where the greatest portion of agriculture is produced, rising water demands have resulted in the primary aquifer being overdrawn, which is now set to be depleted within the next few years (IRG, 2011). This means that melt water from the glaciers will need to be increasingly well-managed, and small fluctuations in its flow could result in a negative chain reaction for the agriculture industry.

The agricultural sector is also notably susceptible to temperature variations. A study of temperature rise triggered by the 1997 ENSO event resulted in a 57% loss in crop production, devastating farmers nationwide, despite the increased precipitation brought about by the event (IRG, 2011). There is evidence, however, that indicates that rising temperatures in the highlands could open the door for higher production in those regions, but simultaneously jeopardize the coastal farms currently providing the bulk of the gross product (IRG, 2011).

In the highlands, glaciers have typically provided continuous melt water to sustain river flows through droughts and the dry season, glacier fed rivers and streams will have lower dry season flows and increased variability with a diminishing mass of glaciers upstream. As mentioned before, mass balance anomalies are negative during El Niño and positive during La Niña events, larger glacier melt in an El Niño year will bring too much water when water is plentiful, and too little when water demand is greater. This will make water storage, efficient irrigation, and water use systems highly significant in Peruvian livelihoods.

Another impact of glacial melt is the formation and/or increase in the area and volume of glacial lakes and the resulting potential for glacial lake outburst floods. Melting glaciers create and/or expand mountain lakes. The destabilization of these lake walls can have devastating effects for people and land below them. In addition, high levels of glacial melt can damage water storage and make distribution systems vulnerable, as increased runoff can create flash floods that carry a large amount of rock and glacial debris.

Fishing, along with agriculture, is one of the largest contributors to the Peruvian GDP and this important source of food supply is dependent upon climate and ENSO. Under normal circumstances, the westward blowing winds off the coast of Peru result in cold nutrient rich water rising to the surface to displace the divergent warm water. The nutrients rising with the cold water form important feed for zooplankton, which sit at the bottom of the food chain and are subsequently crucial for the fishing industry. During El Niño periods, coastal upwelling processes off the coasts of Peru are suppressed resulting in migration of economically important fish populations such as Anchovy (Glantz, 1996), which represent 75% of Peru's fish catch and over 2 billion dollars in exports as of 2008 (IRG, 2011).

Each of these threats, whether they arise out of the agriculture, fishing, or water security sectors, pose a great risk to the economic stability and growth of Peru as a whole. With so many regions of high value (e.g. Andes glaciers and the Altiplano) being so prone to climate induced changes, Peruvian society will undoubtedly be forced to make adaptations and prepare for the worst case climate change scenario.

Conclusion

Peru, with its diverse topography, is host to highly variant landscapes and climates. Consequently, it is not reasonable to expect the country's climate to change uniformly in coming years; rather, by dividing the country into three main regions, it is possible to draw a picture of how different areas will respond to precipitation and temperature changes. The deserts and coastal regions, home to the heart of Peruvian agriculture, are expected to increase in temperature by 4°C over the next century. Mid century, precipitation in the Amazon basin is expected to trend upward during the wet season and trend downward in the dry season. Worst case temperature projections conclude a 4°C increase from current climatological means. In the Andes highlands, glaciers supply crucial water to a myriad of communities and industries. While the models have difficulty simulating climate in this region, it has become well-established that the glaciers are melting at an increased rate, raising geomorphic and water security concerns that will be of immediate relevance to all Peruvians. Overall, despite drastic differences between regions, one notable similarity arises; the climate of Peru is changing, and is expected to continue to change in a way that seriously threatens the livelihoods of its inhabitants.

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